

5. RADIONUCLIDE DATA

5.1 OVERVIEW

This section describes current radionuclide measurement techniques in use at EML and their associated data. A radionuclide is identified by its three principal characteristics: half-life, type of emission, and energy of the emission. Sometimes overlooked in the process are progeny radionuclides with their own particular characteristics.

In the 1960s, routine measurements were being performed at EML for α , β , and γ radionuclides. Measurements in both the Frisch grid ion chamber and the solid-state surface barrier detection systems were used to identify γ energies in sources in properly calibrated systems. Contained in this section is a table of γ emitters by energy, especially linked to the charts of the naturally occurring radionuclides, which assists in radionuclide identification in separated samples and in radionuclide purity checks.

Routine measurement of β emitters is performed on counters designed at EML. These counters have a very low background count rate due to anticoincidence counting techniques. The overall counting efficiencies are comparable to proportional counters. Radiochemical purity is typically assessed by decay measurements.

Use of NaI(Tl) γ spectrometry detection systems provides poorly resolved spectra compared with the Ge(Li) and intrinsic Ge systems presently in use. The resolution of these present systems require sophisticated computer algorithms to identify energies associated with particular radionuclides. It is most important that the energies and the branching ratios used at any facility be documented and a table of γ emitters in the environment is included.

Contained in the natural decay series are charts of three natural radionuclide series and the man-made americium series. Pertinent data are included in these charts.

5.2 ALPHA

5.2.1 SCOPE

The tables on " emitters by atomic number and by energy have been developed for internal use at EML. The present tables are revisions compiled from the data given in Table of Radioactive Isotopes by Browne et al. (1986).

REFERENCE

Browne, E., R. B. Firestone and V. S. Shirley (Editors)
Table of Radioactive Isotopes
John Wiley and Sons, Inc., New York (1986)

ALPHA EMITTERS BY ATOMIC NUMBER

Most short-lived nuclides are included as principal members of
the natural decay series (see Section 5.6)

Radionuclide	$t_{1/2}$	Isotopic Abundance (%)	" Emission (when not 100%)	E_{MeV}
60 ^{144}Nd	$2.1 \times 10^{15} \text{ y}$	23.8		1.83
62 ^{147}Sm	$1.03 \times 10^8 \text{ y}$			2.46
62 ^{147}Sm	$1.06 \times 10^{11} \text{ y}$	15.0		2.233
64 ^{148}Gd	75.3 y			3.183
64 ^{152}Gd	$1.79 \times 10^6 \text{ y}$			2.726
64 ^{152}Gd	$1.08 \times 10^{14} \text{ y}$	0.20		2.14
66 ^{154}Dy	$2.9 \times 10^6 \text{ y}$			2.872
72 ^{174}Hf	$2.0 \times 10^{15} \text{ y}$	0.162		2.50
76 ^{186}Os	$2.0 \times 10^{15} \text{ y}$	1.58		2.80
78 ^{190}Pt	$6.0 \times 10^{11} \text{ y}$	<0.02		3.175
83 $^{210\text{m}}\text{Bi}$	$3.00 \times 10^6 \text{ y}$		4.946(55.5%), 4.908(38.8%), 4.569(3.8%)	
83 $^{211}\text{Bi(AcC)}$	2.14 m			6.623(84%), 6.279(16%)
83 $^{212}\text{Bi(ThC')}$	1.0092 h		3.954%	6.090(26.8%), 6.051(70.2%), 5.768(1.7%), 5.707(1.1%)
84 ^{206}Po	8.83 d		5.45%	5.223
84 ^{208}Po	2.898 y			5.116
84 ^{209}Po	102.0 y			4.866
84 $^{210}\text{Po (RaF)}$	138.376 d			5.305
84 $^{212}\text{Po (ThC')}$	298.0 ns			8.784
84 ^{213}Po	4.28 μs			8.375
84 $^{214}\text{Po(RaC')}$	163.69 μs			7.687
84 $^{215}\text{Po(AcC)}$	1.780 ms			7.386
84 $^{216}\text{Po(ThA)}$	150.0 ms			6.779
84 $^{218}\text{Po(RaA)}$	3.05 m			6.003

ALPHA EMITTERS BY ATOMIC NUMBER (Cont'd)

Radionuclide	$t_{1/2}$	Isotopic Abundance (%)	" Emission (when not 100%)	E_{MeV}
85 ^{211}At	7.215 h		41.7%	5.868
85 ^{217}At	32.3 ms			7.067
86 $^{219}\text{Rn}(\text{Em})$	3.96 s			6.819(80.9%), 6.553(12.2%), 6.425(7.5%)
86 $^{220}\text{Rn}(\text{Em, Tn})$	55.6 s			6.288
86 $^{222}\text{Rn}(\text{Em, Rn})$	3.825 d			5.490
87 ^{221}Fr	4.9 m			6.341(83.4%), 6.243(1.3%), 6.127(15.1%)
88 $^{223}\text{Ra}(\text{AcX})$	11.43 d			5.747(9.5%), 5.716(52.5%), 5.607(24.2%), 5.540(9.2%), others
88 $^{224}\text{Ra}(\text{ThX})$	3.66 d			5.686(95.1%), 5.449(4.9%)
88 ^{226}Ra	1600.0 y			4.784(94.5%), 4.601(5.6%)
89 ^{225}Ac	10.0 d			5.829(51.6%), 5.793(18.1%), 5.791(8.6%), 5.731(10%), 5.637(4.5%), others
90 $^{227}\text{Th}(\text{Rd Ac})$	18.718 d			6.038%(24.5%), 5.978(23.4%), 5.757(20.3%), 5.714(4.9%), 5.710(8.2%), others
90 $^{228}\text{Th}(\text{Rd Th})$	1.913 y			5.423(72.7%), 5.341(26.7%)
90 ^{229}Th	7340.0 y			5.050(5.2%), 4.968(6.0%), 4.901(10.2%), 4.845(56.2%), 4.814(9.3%), others
90 $^{230}\text{Th}(\text{Io})$	7.54×10^4 y			4.688(76.3%), 4.621(23.4%)
90 $^{232}\text{Th}(\text{Th})$	1.405×10^{10} y	100.		4.010(77%), 3.952(23%)
91 $^{231}\text{Pa}(\text{Pa})$	3.276×10^4 y			5.059(11%), 5.029(20%), 5.013(25.4%), 4.951(22.8%), 4.734(8.4%), others
92 ^{230}U	20.8 d			5.889(67.4%), 5.818(32%), others
92 ^{232}U	68.9 y			5.320(68.6%), 5.264(31.2%)
92 ^{233}U	1.592×10^5 y			4.825(84.4%), 4.783(13.2%), others
92 $^{234}\text{U}(\text{UII})$	2.454×10^5 y	0.0055		4.776(72.5%), 4.724(27.5%)

ALPHA EMITTERS BY ATOMIC NUMBER (Cont'd)

Radionuclide	$t_{1/2}$	Isotopic Abundance (%)	" Emission (when not 100%)	E_{MeV}
92 $^{235}\text{U}(\text{AcU})$	$7.037 \times 10^8 \text{ y}$	0.7200	4.597(5%), 4.556(4.2%), 4.395(55%), 4.364(~11%), 4.218(5.7%), others	
92 ^{236}U	$2.342 \times 10^7 \text{ y}$		4.494(74%), 4.445(26%)	
92 $^{238}\text{U}(\text{UI})$	$4.468 \times 10^9 \text{ y}$	99.2745	4.196(77%), 4.147(23%)	
93 ^{237}Np	$2.14 \times 10^6 \text{ y}$		4.873(2.6%), 4.988(47%), 4.772(25%), 4.766(8%), 4.640(6.2%), others	
94 ^{236}Pu	2.851 y		5.768(68.1%), 5.721(31.7%)	
94 ^{238}Pu	87.74 y		5.499(71.6%), 5.456(28.3%)	
94 ^{239}Pu	$2.411 \times 10^4 \text{ y}$		5.156(73.2%), 5.143(15.1%), 5.105(10.6%)	
94 ^{240}Pu	6563.0 y		5.168(73.5%), 5.124(26.4%)	
94 ^{242}Pu	$3.763 \times 10^5 \text{ y}$		4.901(78%), 4.856(22.4%)	
94 ^{244}Pu	$8.26 \times 10^7 \text{ y}$		4.589(80.5%), 4.546(19.4%)	
95 ^{241}Am	432.7 y		5.486(85.2%), 5.443(12.8%), 5.388(1.4%)	
95 ^{243}Am	7380.0 y		5.277(88%), 5.234(11%), 5.180(1.1%)	
96 ^{240}Cm	27.0 d		6.291(70.6%), 6.248(28.8%)	
96 ^{242}Cm	162.94 d		6.113(74%), 6.070(25%)	
96 ^{243}Cm	28.5 y		6.067(1.5%), 6.059(5%), 5.992(6.5%), 5.786(73.3%), 5.742(10.6%), others	
96 ^{244}Cm	18.11 y		5.805(76.4%), 5.763(23.6%), others	
96 ^{245}Cm	8500.0 y		5.362(93.2%), 5.304(5.0%), others	
96 ^{246}Cm	4730.0 y		5.386(79%), 5.343(21%)	
96 ^{247}Cm	$1.56 \times 10^7 \text{ y}$		5.266(13.8%), 5.210(5.7%), 4.869(71%), 4.818(4.7%), others	

ALPHA EMITTERS BY ATOMIC NUMBER (Cont'd)

Radionuclide	$t_{1/2}$	Isotopic Abundance (%)	" Emission (when not 100%)	E_{MeV}
96 $^{248}\text{Cm}^*$	3.40×10^5 y	91.7%	5.078(81.9%), 5.035(18%)	
97 ^{247}Bk	1380.0 y		5.795(5.5%), 5.712(17%), 5.687(13%), 5.532(45%), 5.501(7%), others	
98 ^{246}Cf	1.487 d		6.750(78.0%), 6.709(21.8%)	
98 ^{248}Cf	334.0 d		6.262(83.0%), 6.220(17.0%)	
98 ^{249}Cf	350.6 y		6.194(2.2%), 6.140(1.1%), 5.945(4%), 5.903(2.8%), 5.812(84.4%), others	
98 ^{250}Cf	13.09 y		6.031(84.5%), 5.989(15.1%)	
98 ^{251}Cf	898.0 y		6.074(2.7%), 6.014(11.6%), 5.851(27%), 5.812(4.2%), 5.677(35%), others	
98 $^{252}\text{Cf}^*$	2.646 y	96.9%	6.118(84%), 6.076(15.8%)	
99 $^{252}\text{Es}^*$	1.291 y	76.4%	6.632(79.8%), 6.562(13.5%), 6.483(2.2%), others	
99 ^{253}Es	20.4 d		6.633(89.8%), 6.592(6.6%), others	
99 ^{254}Es	275.7 d		6.427(93.1%), 6.416(1.8%), 6.357(2.6%)	
99 $^{255}\text{Es}^*$	39.8 d	8.0%	6.300(87.5%), 6.260(10.0%), 6.213(2.5%)	
100 ^{52}Fm	1.058 d		7.04(~85%), 6.999(~15%)	
100 $^{253}\text{Fm}^*$	3.00 d	12.0%	7.024(6.7%), 6.943(42.7%), 6.901(9.8%), 6.847(8.5%), 6.674(23.3%), others	
100 ^{255}Fm	20.07 h		7.022(93.4%), 6.963(5.0%), others	
100 ^{257}Fm	100.5 d		6.696(3.4%), 6.519(93.5%), 6.441(2.0%)	
101 ^{258}Md	55.4 d		6.790(28%), 6.716(72%)	

*Relative " -intensity normalized to 100 " -decays.

ALPHA EMITTERS BY ENERGY (MeV)*

3.8-4.0	4.0-4.2	4.2-4.4	4.4-4.6	4.6-4.8	4.8-5.0	5.0-5.2	5.2-5.4	5.4-5.6	5.6-5.8	5.8-6.0	6.0-6.2	6.2-6.4
Uranium Series:												
^{238}U		^{234}U		^{210}Po		^{222}Rn				^{218}Po		
		^{230}Th										
		^{226}Ra										
Thorium Series:												
^{232}Th	^{232}Th				^{228}Th		^{228}Th		^{212}Bi		^{212}Bi	^{220}Rn
							^{224}Ra		^{224}Ra			
Actinium Series:												
^{235}U	^{235}U	^{231}Pa	^{231}Pa	^{231}Pa				^{223}Ra		^{227}Th	^{227}Th	
Americium Series:												
	^{237}Np				^{241}Am		^{241}Am		^{225}Ac		^{225}Ac	^{221}Fr
	^{233}U	^{233}U	^{229}Th	^{229}Th								^{221}Fr
All Emitters:												
^{232}Th	^{232}Th	^{235}U	$^{210\text{m}}\text{Bi}$	^{226}Ra	^{209}Po	^{208}Po	^{206}Po	^{222}Rn	^{212}Bi	^{211}At	^{212}Bi	^{211}Bi
		^{238}U	^{235}U	^{230}Th	$^{210\text{m}}\text{Bi}$	^{229}Th	^{210}Po	^{223}Ra	^{223}Ra	^{225}Ac	^{218}Po	^{220}Rn
			^{236}U	^{231}Pa	^{229}Th	^{231}Pa	^{228}Th	^{224}Ra	^{224}Ra	^{227}Th	^{221}Fr	^{221}Fr
			^{244}Pu	^{233}U	^{231}Pa	^{239}Pu	^{232}U	^{228}Th	^{225}Ac	^{230}U	^{227}Th	^{240}Cm
				^{234}U	^{233}U	^{240}Pu	^{241}Am	^{238}Pu	^{227}Th	^{243}Cm	^{242}Cm	^{248}Cf
					^{237}Np	^{237}Np	^{243}Am	^{243}Am	^{241}Am	^{236}Pu	^{244}Cm	^{243}Cm
						^{242}Pu	^{248}Cm	^{245}Cm	^{247}Bk	^{243}Cm	^{249}Cf	^{254}Es
						^{247}Cm		^{246}Cm		^{244}Cm	^{250}Cf	^{250}Cf
								^{247}Cm		^{247}Bk	^{251}Cf	^{251}Cf
										^{251}Cf		^{252}Cf

*A listing may denote more than one energy.

SPECIFIC ACTIVITY OF SELECTED ALPHA EMITTERS
(in order of ascending atomic numbers)

Nuclide	$t_{1/2}$ (y)	mCi mg ⁻¹	MBq mg ⁻¹
^{210m} Bi	3.00 x 10 ⁶	5.7 x 10 ⁻⁴	2.11 x 10 ⁻²
²⁰⁸ Po	2.898	593.1	2.19 x 10 ⁴
²⁰⁹ Po	102	16.8	6.22 x 10 ²
²²⁶ Ra	1600	0.989	3.66 x 10 ¹
²²⁸ Th	1.913	819.6	3.03 x 10 ⁴
²²⁹ Th	7340	0.213	7.88
²³⁰ Th	7.54 x 10 ⁴	2.062 x 10 ⁻²	7.63 x 10 ⁻¹
²³² Th	1.405 x 10 ¹⁰	1.0969 x 10 ⁻⁷	4.06 x 10 ⁻⁶
²³¹ Pa	3.276 x 10 ⁴	4.724 x 10 ⁻²	1.75
²³² U	68.9	22.4	8.29 x 10 ²
²³³ U	1.592 x 10 ⁵	9.64 x 10 ⁻³	3.57 x 10 ⁻¹
²³⁴ U	2.454 x 10 ⁵	6.225 x 10 ⁻³	2.30 x 10 ⁻¹
²³⁵ U	7.037 x 10 ⁸	1.922 x 10 ⁻⁶	7.11 x 10 ⁻⁵
²³⁶ U	2.342 x 10 ⁷	6.508 x 10 ⁻⁵	2.41 x 10 ⁻³
²³⁸ U	4.468 x 10 ⁹	3.36237 x 10 ⁻⁷	1.24 x 10 ⁻⁵
²³⁷ Np	2.140 x 10 ⁶	7.05 x 10 ⁻⁴	2.61 x 10 ⁻²
²³⁶ Pu	2.851	531.3	1.97 x 10 ⁴
²³⁸ Pu	87.74	17.119	6.33 x 10 ²
²³⁹ Pu	2.411 x 10 ⁴	6.204 x 10 ⁻²	2.30
²⁴⁰ Pu	6563	0.22696	8.40

SPECIFIC ACTIVITY OF SELECTED ALPHA EMITTERS (Cont'd)
(in order of ascending atomic numbers)

Nuclide	$t_{1/2}$ (y)	mCi mg^{-1}	MBq mg^{-1}
^{242}Pu	3.763×10^5	3.962×10^{-3}	1.45×10^{-1}
^{241}Am	432.7	3.428	1.27×10^2
^{243}Am	7380	0.1993	7.37
^{242}Cm	4.461×10^{-1}	3311.4	1.23×10^5
^{243}Cm	28.5	51.6	1.91×10^3
^{244}Cm	18.11	80.90	2.99×10^3
^{245}Cm	8500	0.1717	6.35
^{248}Cm	3.40×10^5	4.24×10^{-3}	1.57×10^{-1}
^{247}Bk	1380	1.05	3.89×10^1
^{248}Cf	9.1444×10^{-1}	1579	5.84×10^4
^{249}Cf	350.6	4.095	1.52×10^2
^{250}Cf	13.08	109.3	4.04×10^3
^{251}Cf	898	1.59	5.88×10^1
^{252}Cf	2.645	536.3	1.98×10^4
^{252}Es	1.291	1098	4.06×10^4
^{254}Es	7.54825×10^{-1}	1865	6.90×10^4

5.3 BETA

5.3.1 SCOPE

The table of \$ emitters presented here is useful in identifying unknown \$ emitters whose energies and possibly half-lives have been determined by standard laboratory techniques, including the Harley-Hallden method (see Procedure 4.5.2.1). It is also a handy guide to \$ emitting isotopes for applications requiring specific half-lives and/or energies.

The original table was developed by Hallden (1955). Since that time there have been three revisions based on "current" published compilations. The present table was compiled from the Table of Isotopes (Lederer and Shirley, 1978).

The emitter energy listings are the maximum \$ energy (E_{max}). Isotopes decaying the emission of \$ particles of different energies are listed in the energy group corresponding to each E_{max} , provided that the branch contributes > 5% of the total \$ emission. Isotopes with longer-lived parents are also listed under the parent half-life. In the case of multiple long-lived parents, the nuclide is listed under the half-life of the nearest long-lived parent, as well as its own half-life.

REFERENCES

- Hallden, N. A.
"Beta Emitters by Energy and Half-life"
Nucleonics, 13, 78-79 (1955)
- Lederer, C. and V. S. Shirley (Editors)
Table of Isotopes - Seventh Edition
John Wiley and Sons, New York, NY (1978)

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	09.-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
6-12 h		²³⁴ Pa	¹⁵⁶ Sm	⁶² Zn	⁵² Fe	⁹¹ Sr	¹⁶³ Tb	⁷³ Se	²⁰⁸ Tl	^{152m} Eu		⁷⁷ Ge	¹²⁸ Sb	⁹¹ Sr	⁹³ Y	⁶² Cu	⁶⁶ Ga
			²¹² Pb	⁹¹ Sr	⁷⁷ Ge	¹³⁵ I	¹⁸⁴ Ta	⁷⁷ Ge	²¹² Bi	²⁰⁸ Tl		²¹² Bi					
			²²⁸ Ac	¹³⁵ I	^{82m} Rb	¹³⁵ Xe	²⁰⁸ Tl	⁹¹ Sr		²²⁸ Ac		²²⁸ Ac					
			²⁴⁴ Am	^{152m} Eu	¹⁰¹ Pd	¹⁷¹ Er	²²⁸ Ac	¹³⁵ I		²²⁸ Ac							
				¹⁷¹ Er	¹²⁷ Te	²⁴⁵ Pu		¹⁶³ Tb									
				²¹² Pb	¹⁵⁶ Sm	²⁴⁵ Am		¹⁸⁴ Ta									
				²²⁸ Ac	¹⁷³ Tm												
				²³⁴ Pa	¹⁷³ Tm												
				²³⁴ Pa	^{180m} Ta												
12 h-1 d		¹¹² Pd	²⁸ Mg	⁶⁴ Cu	⁴³ K	⁵⁵ Co	⁸⁶ Y	²⁴ Na	⁵⁵ Co	⁷⁶ Br	⁴² K	¹⁴² Pr		⁷² Ga	²⁸ Al	⁴² K	
			⁴³ K	⁶⁴ Cu	⁶⁹ Zn	¹⁰⁹ Pd	⁹⁷ Nb	¹³³ I	⁷² Ga		⁹⁷ Zr	¹⁸⁸ Re			¹⁵² Tb	⁷² Ga	
			⁹⁶ Nb	¹¹⁹ Te	⁹⁰ Nb	¹³⁰ I		¹⁵⁷ Eu	⁸⁶ Y		¹¹² Ag	¹⁹⁴ Ir				⁷⁶ Br	
			¹⁹⁷ Pt	¹³⁰ I	⁹⁶ Nb	¹⁵⁰ Eu		¹⁸⁷ W	⁹⁰ Nb		¹⁵² Tb	^{240m} Np				¹¹² Ag	
			²³⁶ Np	¹⁵⁹ Gd	¹⁵⁷ Eu	¹⁵⁷ Eu		^{240m} Np	^{240m} Np		¹⁸⁸ Re					¹¹² Ag	
			²⁴⁰ U	¹⁸⁷ W	¹⁵⁹ Gd	¹⁵⁹ Gd				¹⁹⁴ Ir							
				¹⁸⁷ W	¹⁹⁷ Pt												
				¹⁸⁷ W	^{240m} Np												
				¹⁹⁷ Pt													
				^{200m} Au													
				²³⁶ Np													
				^{240m} Np													
				²⁴² Am													
				²⁴² Am													
				²⁴⁸ Bk													

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
1-3 d	²³¹ Th	⁶⁶ Ni ⁷² Zn	⁶⁷ Cu ⁶⁷ Cu	⁴⁸ Sc ⁷¹ As	⁵⁷ Ni ¹⁴³ Ce	¹⁴⁹ Pm	⁶⁹ Ge ⁸³ Sr	¹²² Sb ¹³¹ Te	⁶⁶ Cu ⁷² Ga	⁷⁶ As ¹⁶⁶ Ho	¹²² Sb ¹³¹ Te	⁹⁰ Y ¹⁶⁶ Ho	⁷⁶ As ¹⁴⁰ La	⁶⁶ Cu ⁷² Ga	⁷⁶ As ⁷² As		
		¹⁰⁵ Rh	⁷² Zn	⁷⁷ As	¹⁴³ Ce	¹⁵¹ Pm	⁹⁹ Mo	¹⁴⁰ La	¹³¹ Te	¹⁶⁶ Ho		¹³¹ Te	¹⁴⁰ La	⁷² As			
		¹⁷² Er	⁸² Br	⁷⁹ Kr	¹⁴⁹ Pm	¹⁸⁹ Re	¹⁹⁸ Au	¹¹⁵ Cd	¹⁴³ Ce	¹⁷² Tm	¹⁷² Tm						
		¹⁷² Tm	⁹⁹ Mo	¹⁰⁵ Rh	¹⁵¹ Pm		¹⁴⁰ La										
	²³¹ Th	¹²¹ Sn	¹¹⁵ Cd	¹⁵¹ Pm			¹⁴³ Ce										
	²³¹ Th	^{131m} Te	^{131m} Te	¹⁵¹ Pm													
	²³¹ Th	¹⁵¹ Pm	¹⁴⁰ La	¹⁵³ Sm													
	²³⁸ Np	¹⁷² Er	¹⁴³ Ce	¹⁵³ Sm			¹⁵¹ Pm										
	²³⁸ Np	¹⁷² Tm	¹⁵¹ Pm	¹⁷² Tm			¹⁵¹ Pm										
	²³⁸ Np	²³² Pa	¹⁵³ Sm	¹⁸⁹ Re			¹⁹³ Os										
		²³⁹ Np	¹⁹³ Os	¹⁹³ Os	²²⁶ Ac		²²⁶ Ac										
		²³⁹ Np	¹⁹³ Os	²³⁹ Np			²³⁸ Np										
		^{245m} Es					^{245m} Es										

Note: Where the symbol for a nuclide appears more than once in any grouping it indicates emission of more than one energy.

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T1/2	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
3-5 d	¹⁷⁵ Yb	¹³² Te	⁴⁷ Sc	⁴⁷ Ca	⁸⁹ Zr	¹³² I	¹²⁷ Sb	¹²⁷ Sb	¹²⁴ I	¹⁶⁶ Ho	⁴⁷ Ca	¹²⁴ I	¹⁴⁰ Pr	¹³⁴ La		²¹⁴ Bi	
		¹⁹⁹ Au	¹⁶⁶ Dy	⁴⁷ Sc	¹²⁷ Sb	¹⁸⁶ Re	¹³² I		¹²⁷ Sb	¹⁶⁶ Ho		¹³² I					
		¹⁹⁹ Au	¹⁶⁶ Dy	¹²⁷ Te	¹³² I	¹⁸⁶ Re			¹³² I	²¹⁴ Bi							
			¹⁷⁵ Yb	²¹⁴ Pb	²¹⁴ Pb	²¹⁴ Bi			²¹⁴ Bi								
			¹⁹⁹ Au														
			²¹⁴ Bi														
5-10 d	²³⁷ U	¹⁷⁷ Lu	¹³¹ I	⁵² Mn		¹¹¹ Ag	²¹⁰ Bi			¹⁴⁸ Pm			¹²⁵ Sn	⁷² As		⁷² As	
		¹⁹⁶ Au	¹³³ Xe	¹¹¹ Ag		¹⁴⁸ Pm							¹⁴⁸ Pm				
		²³⁷ U	¹⁶¹ Tb	¹³¹ I													
			¹⁶⁹ Er	¹⁶¹ Tb													
			¹⁷⁷ Lu	¹⁶¹ Tb	¹⁸³ Ta												
10-13 d	²⁴⁶ Pu	¹⁴⁰ Ba	¹⁴⁰ La	¹⁴⁰ Ba	¹⁴⁰ Ba	¹⁴⁰ La	¹⁴⁰ La	¹⁴⁰ La	¹⁴⁰ La	²⁰⁷ Tl	²⁴⁶ Am	¹²⁶ Sb	¹⁴⁰ La	²⁴⁶ Am			
		¹⁴⁷ Nd	²⁰⁹ Pb	¹⁴⁷ Nd						²¹¹ Pb	²¹³ Bi						
		²⁴⁶ Pu	²¹¹ Pb							²⁴⁶ Am							
13-15 d			¹²⁶ I	¹³⁶ Cs	¹²⁶ I	¹⁴³ Pr	¹²⁶ I			³² P							
			¹³⁶ Cs														
			²²⁵ Ra														

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T1/2	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
15-20 d		¹⁹¹ Os	¹⁵⁶ Eu	⁴⁸ V	⁷⁴ As	⁷⁴ As	¹⁵⁶ Eu	⁷⁴ As		⁸⁶ Rb			¹⁵⁶ Eu				
20-30 d		²⁵³ Cf	¹⁵⁶ Eu	²³⁰ Pa	⁸⁶ Rb				²³⁴ Pa							⁸² Rb	
30-40 d			³³ P	²³³ Pa	²³⁴ Pa	²³⁴ Pa											

Note: Where the symbol for a nuclide appears more than once in any grouping it indicates emission of more than one energy.

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T1/2	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
40-50 d		⁵⁹ Fe ²⁰³ Hg	⁵⁹ Fe ^{148m} Pm ¹⁸¹ Hf	^{148m} Pm					^{115m} Cd								
50-100 d		³⁵ S ⁹⁵ Nb ¹²⁴ Sb ¹⁶⁰ Tb ¹⁹² Ir ²⁵³ Cf	⁴⁶ Sc ⁵⁸ Co ⁹⁵ Zr ¹⁹² Ir ¹⁶⁰ Tb ¹⁸⁵ W ¹⁸⁸ W	¹²⁴ Sb ¹⁶⁰ Tb ¹⁹² Ir ¹⁹² Ir ¹⁸² Ta	¹⁶⁰ Tb	¹²⁴ Sb		⁵⁶ Co ⁸⁹ Sr	⁹¹ Y ¹²⁴ Sb		¹¹⁴ In ¹⁸⁸ Re	¹⁸⁸ Re	¹²⁴ Sb				
100-150 d								¹²³ Sn									
150-200 d		⁴⁵ Ca ¹⁷⁷ Lu	¹⁷⁷ Lu														
200-250 d							¹⁰² Rh										
250 d-1 y	^{110m} Ag	¹⁴⁴ Ce ²⁴⁹ Bk	¹⁴⁴ Ce	^{110m} Ag	²⁵⁰ Bk				⁶⁸ Ga ²⁵⁰ Bk					¹⁴⁴ Pr			
1-2 y	¹⁰⁶ Rh ¹⁷¹ Tm									¹⁰⁶ Rh				¹⁰⁶ Rh	¹⁰⁶ Rh		

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
2-3 y	¹³⁴ Cs	¹²⁵ Sb	¹²⁵ Pm	¹²⁵ Sb	²² Na												
3-5 y		¹⁵⁵ Eu	¹⁵⁵ Eu		¹²⁵ Sb	¹³⁴ Cs											
5-10 y	¹⁹⁴ Os	¹⁵⁴ Eu	⁶⁰ Co	¹⁵⁴ Eu	¹⁴⁶ Pm		²²⁸ Ac			¹⁵⁴ Eu	¹⁹⁴ Ir	¹⁹⁴ Ir					
	²²⁸ Ra		²²⁸ Ac	²²⁸ Ac		¹⁵⁴ Eu			²²⁸ Ac	²²⁸ Ac		²²⁸ Ac					

Note: Where the symbol for a nuclide appears more than once in any grouping it indicates emission of more than one energy.

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
10-20 y	³ H ²⁴¹ Pu			⁸⁵ Kr ¹¹³ Cd ¹⁵² Eu ¹⁵⁴ Eu			¹⁵² Eu		¹⁵⁴ Eu								
20-30 y	²¹⁰ Pb ²¹⁰ Pb ²²⁷ Ac			⁹⁰ Sr			²¹⁰ Bi				⁹⁰ Y						
30-50 y				¹³⁷ Cs			¹³⁷ Cs	⁴⁴ Sc									
50-100 y	¹⁵¹ Sm		^{121m} Sn														
>100 y	⁶³ Ni ⁹³ Zr ¹⁰⁷ Pd ^{166m} Ho ¹⁸⁷ Re ²²⁷ Ac ²²⁸ Ra ²²⁸ Ra ²³¹ Th	¹⁴ C ³² Si ⁷⁹ Se ⁸⁷ Rb ⁹⁹ Tc ¹²⁶ Sn ¹²⁹ I ¹³⁵ Cs ¹³⁸ La ²³¹ Th	⁹⁴ Nb ⁹⁸ Tc ¹¹⁵ In ¹⁸² Ta ²²⁵ Ra ²⁴² Am ²⁴² Am	¹⁰ Be ³⁹ Ar ¹⁷⁶ Lu ¹⁸² Ta ²³³ Pa ²⁴² Am	³⁶ Cl ¹⁵⁸ Tb ²³⁸ Np		²⁶ Al ⁴⁰ K		³² P	¹²⁶ Sb	^{234m} Pa						

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

$T_{1/2}$	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
	^{231}Th																

Note: Where the symbol for a nuclide appears more than once in any grouping it indicates emission of more than one energy.

5.4 GAMMA

5.4.1 SCOPE

Presented here is a tabulation of γ rays and nuclides that are common to environmental analyses. These data may be useful for interpreting either field or laboratory measurements.

As an aid in verifying nuclide identifications, two additional γ -ray lines are included when possible as E2 and E3.

The following special notations are used in the table:

<u>Symbol</u>	<u>Meaning</u>
%	ratio of γ -rays to disintegrations.
X	indicates X-ray.
KX, LX	sum of K or L X-rays.
D	indicates a doublet.
T	indicates a triplet.
*	indicates annihilation radiation.
Long	in half-life column is used for all members of the primordial series, % refers to U or Th decays.

REFERENCE

Browne, E., R. B. Firestone and V. S. Shirley (Editors)

Table of Radioactive Isotopes

John Wiley and Sons, Inc., New York (1986)

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
14.4	⁵⁷ Co	9.5	272D	122.1	85.5	136.5	10.7	Activation
26.3	²⁴¹ Am	2.4	433Y	59.5	35.7	17.0LX	38.7	²⁴¹ Pu
30.0	¹⁴⁰ Ba	13.6	12.8D	162.7	6.2	304.9	4.3	Fallout
39.6	¹²⁹ I	7.5	1.6E7	30.0KX	70.8			Fission
39.9	²¹² Bi	1.1	Long	727.3	6.7	1620.7	1.5	²³² Th
40.6	⁹⁹ Mo	1.1	65.9H	18.3X	3.2	140.5	3.5	Fallout
46.5	²¹⁰ Pb	4.1	22.3Y					²³⁸ U
49.8	¹³² Te	14.4	78.2H	30.0KX	70.9	111.9	1.9	Fallout
53.2	¹³³ Ba	2.2	10.5Y	81.0	34.2	31.0KX	101.3	Activation
59.5	²³⁷ U	32.8	6.75D	101.1	26.0	208.0	22.0	Fallout
59.5	²⁴¹ Am	35.7	433Y	26.3	2.4	17.0LX	38.7	²⁴¹ Pu
60.0	¹⁵⁵ Eu	1.1	4.96Y	86.5	30.4	105.3	20.6	Fallout
61.5	²³⁹ Np	1.0	2.36D	14.3LX	56.1	101.0KX	38.9	Fallout
63.3	²³⁴ Th	3.8	Long	92.6D	5.4			²³⁸ U
66.9	¹³⁶ Cs	12.5	13.2D	34.0KX	17.6	86.4	6.3	Fission
74.8X	²¹⁴ Pb	6.5	Long	77.1X	11.0	87.3X	3.9	²³⁸ U
74.8X	²¹² Pb	10.5	Long	77.1X	17.7	87.2X	6.3	²³² Th
75.0X	²⁰⁸ Tl	3.6	Long	72.8X	2.1	84.8X	1.3	²³² Th
77.1X	²¹⁴ Pb	11.0	Long	74.8X	6.5	87.2X	3.9	²³⁸ U
77.1X	²¹² Pb	17.7	Long	74.8X	10.5	87.2X	6.3	²³² Th
79.6	¹³³ Ba	3.2	10.5Y	53.2	2.2			Activation
80.1	¹⁴⁴ Ce	1.1	285D	133.5	11.1	696.5	1.3	Fallout
80.2	¹³¹ I	2.6	8.04D	364.5	81.2	284.3	6.1	Fission
81.0	¹³³ Ba	34.2	10.5Y	276.4	7.3	79.6	3.2	Activation
81.0	¹³³ Xe	37.0	5.25D	79.6	0.2	31.0KX	40.1	Fission
84.3X	²²⁸ Th	1.2	1.91Y	12.3X	3.1			²³² Th
86.4	¹³⁶ Cs	6.3	13.2D	66.9	12.5	153.3	7.5	Fission
86.5	¹⁵⁵ Eu	34.0	4.96Y	105.3	20.6	60.0	1.1	Fallout
87.2X	²¹⁴ Pb	3.9	Long	77.1X	11.0	241.9	7.5	²³⁸ U
87.2X	²¹² Pb	6.3	Long	238.6	43.6	77.1X	17.7	²³² Th
88.0	¹⁰⁹ Cd	3.6	463D	23.0KX	99.8			Activation
90.0X	²²⁸ Ac	3.4	Long	93.4X	5.6	99.6	1.3	²³² Th
91.1	¹⁴⁷ Nd	28.0	11.0D	38.5KX	37.4	319.4	2.0	Fallout
92.6D	²³⁴ Th	5.4	Long	63.3	3.8			²³⁸ U
93.4X	²²⁸ Ac	5.6	Long	90.0X	3.4	99.6	1.3	²³² Th
97.1	²³⁷ U	16.0	6.75D	101.0	26.0	208.0	22.0	Fallout
99.6	²²⁸ Ac	1.3	Long	129.0	2.9	209.4	4.1	²³² Th

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
101.1	²³⁷ U	26.0	6.75D	59.5	32.8	208.0	22.0	Fallout
105.3	¹⁵⁵ Eu	20.6	4.96Y	86.5	34.0	60.0	1.1	Fallout
105.4X	²²⁸ Ac	2.0	Long	99.6	1.3	129.0	2.9	²³² Th
106.1	²³⁹ Np	22.7	2.36D	61.5	1.0	117.0KX	11.6	Fallout
109.2	²³⁵ U	1.5	70E7Y	93.4KX	5.5	143.8	10.5	Natural
111.9	¹³² Te	1.9	78.2H	49.8	14.4	116.4	1.9	Fallout
113.9	²³⁷ U	25.0	6.75D	101.1	26.0	208.0	22.0	Fallout
116.3	¹³² Te	1.9	78.2H	111.9	1.9	228.3	88.2	Fallout
121.8	¹⁵² Eu	28.4	13.3Y	344.3	26.6	244.7	7.5	Fallout
122.1	⁵⁷ Co	85.5	273D	136.5	10.7	14.4	9.5	Activation
123.1	¹⁵⁴ Eu	40.5	8.8Y	248.0	6.6	591.8	4.8	Fallout
127.2	¹⁰¹ Rh	73.0	3.3Y	198.0	70.8	325.2	13.4	Fallout
129.0	²²⁸ Ac	2.9	Long	99.6	1.3	209.4	4.1	²³² Th
133.5	¹⁴⁴ Ce	11.1	285D	696.5	1.3	80.1	1.1	Fallout
136.5	⁵⁷ Co	10.7	272D	122.1	85.5	14.4	9.5	Activation
138.0	¹³⁸ Cs	1.5	32.2M	227.7	1.5	462.8	30.7	¹³⁸ Xe
140.5	⁹⁹ Mo	3.5	65.9H	40.6	1.1	181.1	6.1	Fallout
140.5	^{99m} Tc	87.2	6.01H	18.4X	6.1	20.6X	1.2	⁹⁹ Mo
143.8	²³⁵ U	10.5	70E7Y	109.2	1.5	163.4	4.7	Natural
145.4	¹⁴¹ C	48.4	32.5D	37.0KX	17.4			Fission
151.2	^{85m} Kr	75.2	4.48H	304.9	13.7			Fission
153.3	¹³⁶ Cs	7.5	13.2D	86.4	6.3	164.0	4.6	Fission
153.9	¹³⁸ Xe	6.0	14.1M	242.7	3.5	258.4	31.5	Fission
162.7	¹⁴⁰ Ba	6.2	12.8D	304.9	4.3	30.0	13.6	Fallout
163.4	²³⁵ U	4.7	70E7Y	143.8	10.5	185.7	53.0	Natural
164.0	¹³⁶ Cs	4.6	13.2D	153.3	7.5	176.6	13.6	Fission
165.9	¹³⁹ Ce	79.9	138D	34.0KX	79.5			Activation
166.0	⁸⁸ Kr	3.1	2.84H	196.3	26.0	362.3	2.3	Fission
176.3	¹²⁵ Sb	6.8	2.73Y	427.9	29.4	380.4	1.5	Fallout
176.6	¹³⁶ Cs	13.6	13.2D	164.0	4.6	273.7	12.7	Fission
181.1	⁹⁹ Mo	6.1	65.9H	140.5	3.5	366.4	1.2	Fallout
185.7	²³⁵ U	53.0	70E7Y	143.8	10.5	205.3	4.7	Natural
186.1	²²⁶ Ra	3.3	1600Y					Natural
192.3	⁵⁹ Fe	3.1	44.5D	1099.3	56.5	1291.6	43.2	Activation
196.3	⁸⁸ Kr	26.0	2.84H	362.3	2.3	166.0	3.1	Fission
198.0	¹⁰¹ Rh	70.8	3.3Y	127.2	73.0	325.2	13.4	Fallout
205.3	²³⁵ U	4.7	70E7Y	185.7	53.0	143.8	10.5	Natural
208.0	²³⁷ U	22.0	6.75D	59.5	32.8	101.1	26.0	Fallout

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
209.4	²²⁸ Ac	4.1	Long	129.0	2.9	270.3	3.8	²³² Th
227.7	¹³⁸ Cs	1.5	32.2M	138.0	1.5	409.0	4.7	¹³⁸ Xe
228.2	²³⁹ Np	10.7	2.36D	106.1	22.7	277.6	14.2	Fallout
228.3	¹³² Te	88.2	78.2H	116.4	1.9	111.9	1.9	Fallout
233.2	^{133m} Xe	10.3	2.19D	30.0KX	56.3			Fission
238.6	²¹² Pb	43.6	Long	300.0	3.3			²³² Th
240.8	²²⁴ Ra	3.9	Long					²³² Th
241.9	²¹⁴ Pb	7.5	Long	295.1	19.2	352.0	37.1	²³⁸ U
242.7	¹³⁸ Xe	3.5	14.1M	153.9	6.0	258.4	31.5	Fission
244.7	¹⁵² Eu	7.5	13.3Y	121.8	28.4	344.3	26.6	Fallout
248.0	¹⁵⁴ Eu	6.6	8.8Y	123.1	40.5	591.8	4.8	Fallout
249.8	¹³⁵ Xe	90.0	9.10H	608.2	2.9	31.0KX	5.2	Fission
258.4	¹³⁸ Xe	31.5	14.1M	242.7	3.5	396.6	6.3	Fission
262.8	¹³² I	1.4	2.28H	505.9	5.0	522.7	16.1	¹³² Te
270.3	²²⁸ Ac	3.8	Long	209.4	4.1	328.0	3.5	²³² Th
273.7	¹³⁶ Cs	12.7	13.2D	176.6	13.6	340.6	48.6	Fission
276.4	¹³³ Ba	7.1	10.5Y	302.9	18.4	81.0	34.2	Activation
277.3	²⁰⁸ Tl	2.4	Long	510.6	7.8	583.0	30.9	²³² Th
277.6	²³⁹ Np	14.2	2.36D	228.2	10.7	315.9	1.6	Fallout
279.2	²⁰³ Hg	81.5	46.6D	74.6X	12.9			Fallout
284.3	¹³¹ I	6.1	8.04D	364.5	81.2	80.2	2.6	Fission
295.1	²¹⁴ Pb	19.2	Long	351.9	37.1	241.9	7.5	²³⁸ U
300.0	²¹² Pb	3.3	Long	238.6	43.6			²³² Th
302.9	¹³³ Ba	18.4	10.5Y	276.4	7.1	356.0	62.2	Activation
304.9	¹⁴⁰ Ba	4.3	12.8D	162.7	6.2	423.7	3.1	Fallout
304.9	^{85m} Kr	13.7	4.48H	151.2	75.1			Fission
315.9	²³⁹ Np	1.6	2.36D	277.6	14.2	334.3	2.1	Fallout
319.4	¹⁴⁷ Nd	2.0	11.0D	439.9	1.2	91.1	28.0	Fallout
320.1	⁵¹ Cr	9.8	27.7D					Activation
325.2	¹⁰¹ Rh	13.4	3.3Y	127.2	73.0	198.0	70.8	Fallout
328.0	²²⁸ Ac	3.5	Long	270.3	3.8	338.4	12.4	²³² Th
328.8	¹⁴⁰ La	20.7	40.3H	432.5	3.0	487.0	45.9	Fallout
334.3	²³⁹ Np	2.1	2.36D	315.9	1.6	61.5	1.0	Fallout
338.4	²²⁸ Ac	12.4	Long	328.0	3.5	409.6	2.2	232Th
340.6	¹³⁶ Cs	48.6	13.2D	273.7	12.7	818.6	99.8	Fission
344.3	¹⁵² Eu	26.6	13.3Y	244.7	7.5	411.1	2.2	Fallout
352.0	²¹⁴ Pb	37.1	Long	241.9	7.5	295.1	19.2	²³⁸ U
356.0	¹³³ Ba	62.2	10.5Y	302.9	18.4	383.8	8.9	Activation

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
362.3	⁸⁸ Kr	2.3	2.84H	196.3	26.0	834.9	13.0	Fission
364.5	¹³¹ I	81.2	8.04D	637.0	7.3	284.3	6.1	Fission
366.4	⁹⁹ Mo	1.2	65.9H	181.1	6.1	739.5	12.1	Fallout
380.4	¹²⁵ Sb	1.5	2.73Y	176.3	6.8	427.9	29.4	Fallout
383.8	¹³³ Ba	8.9	10.5Y	356.0	62.2	302.9	18.4	Activation
396.6	¹³⁸ Xe	6.3	14.1M	258.4	31.5	401.5	2.2	Fission
401.5	¹³⁸ Xe	2.2	14.1M	434.6	20.3	396.6	6.3	Fission
402.6	⁸⁷ Kr	49.6	76.3M	845.5	7.3	673.9	1.9	Fission
409.0	¹³⁸ Cs	4.7	32.2M	227.7	1.5	462.8	30.7	¹³⁸ Xe
409.6	²²⁸ Ac	2.2	Long	338.4	12.4	463.1	4.6	²³² Th
411.1	¹⁵² Eu	2.2	13.3Y	344.3	26.6	444.0D	3.1	Fallout
415.3	¹⁰² Rh	2.1	2.89Y	418.5	10.6	420.4	3.2	Fallout
418.5	¹⁰² Rh	10.6	2.89Y	415.3	2.1	420.4	3.2	Fallout
420.4	¹⁰² Rh	3.2	2.89Y	418.5	10.6	475.1	95.0	Fallout
423.7	¹⁴⁰ Ba	3.1	12.8D	437.6	1.9	304.9	4.3	Fallout
427.9	¹²⁵ Sb	29.4	2.73Y	380.4	1.5	463.4	10.5	Fallout
432.5	¹⁴⁰ La	3.0	40.3H	487.0	45.9	328.8	20.7	Fallout
434.6	¹³⁸ Xe	20.3	14.1M	401.5	2.2	1114.3	1.5	Fission
437.6	¹⁴⁰ Ba	1.9	12.8D	537.3	24.4	423.7	3.1	Fallout
439.9	¹⁴⁷ Nd	1.2	11.0D	319.4	2.0	531.0	13.1	Fallout
444.0D	¹⁵² Eu	3.1	13.3Y	411.1	2.2	778.9	13.0	Fallout
446.8	^{110m} Ag	3.8	250D	657.8	94.6	620.4	2.8	Activation
462.8	¹³⁸ Cs	30.7	32.2M	547.0	10.8	409.0	4.7	¹³⁸ Xe
463.1	²²⁸ Ac	4.6	Long	409.6	2.2	755.3	1.3	²³² Th
463.4	¹²⁵ Sb	10.5	2.73Y	427.9	29.4	600.5	17.8	Fallout
468.7	^{102m} Rh	2.9	207D	475.1	46.0	556.6	1.9	Fallout
475.1	^{102m} Rh	46.0	207D	468.7	2.9	556.6	1.9	Fallout
475.1	¹⁰² Rh	95.0	2.89Y	628.1	8.5	420.5	3.2	Fallout
475.4	¹³⁴ Cs	1.5	2.06Y	563.2	8.4	569.3	15.4	Fission
477.6	⁷ Be	10.3	53.2D					Cosmic
487.1	¹⁴⁰ La	45.5	40.2H	751.9	4.3	432.6	2.9	Fallout
497.1	¹⁰³ Ru	89.5	39.6D	610.3	5.6			Fallout
505.9	¹³² I	5.0	2.28H	262.8	1.4	522.7	16.1	¹³² Te
510.6	²⁰⁸ Tl	7.8	Long	277.3	2.4	583.0	30.9	²³² Th
511.0*	⁶⁵ Zn	2.9	244D	1115.5	50.8			Activation
511.0*	⁵⁸ Co	30.0	70.9D	810.8	99.5			Activation

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
511.0*	²² Na	180.8	2.60Y	1274.5	99.9			Cosmic
511.9	¹⁰⁶ Ru	20.7	372D	1050.4	1.5	621.9	9.8	Fallout
514.0	⁸⁵ Sr	99.3	64.8D	13.4KX	50.6	15.0KX	8.7	Activation
522.7	¹³² I	16.1	2.28H	505.9	5.0	547.0	1.3	¹³² Te
526.6	^{135m} Xe	81.2	15.7M	30.0KX	14.0			Fission
531.0	¹⁴⁷ Nd	13.1	11.0D	439.9	1.2	319.4	2.0	Fallout
537.3	¹⁴⁰ Ba	24.4	12.8D	437.6	1.9	423.7	3.1	Fallout
547.0	¹³⁸ Cs	10.8	32.2M	462.8	30.7	871.7	5.1	¹³⁸ Xe
547.0	¹³² I	1.3	2.28H	522.7	16.1	621.2	~2.0	¹³² Te
556.6	^{102m} Rh	1.9	207D	475.1	46.0	628.1	5.5	Fallout
563.2	¹³⁴ Cs	8.4	2.06Y	475.4	1.5	569.3	15.4	Fission
569.3	¹³⁴ Cs	15.4	2.06Y	563.2	8.4	604.7	97.6	Fission
569.2	²⁰⁷ Bi	97.8	32.2Y	1063.1	74.9	1769.7	6.9	Fallout
583.0	²⁰⁸ Tl	30.9	Long	510.6	7.8	860.3	4.3	²³² Th
591.8	¹⁵⁴ Eu	4.8	8.8Y	248.0	6.6	692.5	1.7	Fallout
600.5	¹²⁵ Sb	17.8	2.73Y	463.4	10.5	606.6	5.0	Fallout
602.7	¹²⁴ Sb	97.8	60.2D	645.9	7.4	709.3	1.4	Fallout
604.7	¹³⁴ Cs	97.6	2.06Y	795.9	85.4	569.3	15.4	Fission
606.6	¹²⁵ Sb	5.0	2.73Y	600.5	17.8	635.9	11.3	Fallout
608.2	¹³⁵ Xe	2.9	9.10H	249.8	90.0	31.6KX	5.2	Fission
609.3	²¹⁴ Bi	46.1	Long	665.4	1.6	768.4	4.9	²³⁸ U
610.3	¹⁰³ Ru	5.6	39.3D	497.1	88.7			Fallout
620.4	^{110m} Ag	2.8	250D	657.8	94.6	446.8	3.8	Activation
621.2	¹³² I	~2.0	2.28H	547.1	1.3	630.3	13.8	¹³² Te
621.9	¹⁰⁶ Ru	9.8	372D	511.9	20.7	1050.4	1.5	Fallout
628.1	^{102m} Rh	5.5	207D	556.6	1.9	1103.2	2.9	Fallout
628.1	¹⁰² Rh	8.5	~2.9Y	475.1	95.0	631.3	56.0	Fallout
630.3	¹³² I	13.8	2.28H	621.2	~2.0	650.6	2.7	¹³² Te
631.3	¹⁰² Rh	56.0	~2.9Y	628.1	8.5	692.4	1.8	Fallout
635.9	¹²⁵ Sb	11.3	2.73Y	606.6	5.0	671.4	1.8	Fallout
637.0	¹³¹ I	7.3	8.04D	364.5	81.2	722.9	1.8	Fission
645.9	¹²⁴ Sb	7.4	60.2D	602.7	97.8	709.3	1.4	Fallout
650.6	¹³² I	2.7	2.28H	630.3	13.8	667.7	98.7	¹³² Te
657.8	^{110m} Ag	94.6	250D	620.4	2.8	677.6	10.4	Activation
661.7	¹³⁷ Cs	85.2	30.0Y	33.0KX	7.1			Fallout
665.4	²¹⁴ Bi	1.6	Long	609.3	46.1	768.4	4.9	²³⁸ U
667.7	¹³² I	98.7	2.28H	650.6	2.7	669.9	4.9	¹³² Te

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
669.9	¹³² I	4.9	2.28H	667.7	98.7	671.6	5.2	¹³² Te
671.4	¹²⁵ Sb	1.8	2.73Y	635.9	11.3	606.6	5.0	Fallout
671.6	¹³² I	5.2	2.28H	669.9	4.9	727.D	5.4	¹³² Te
673.9	⁸⁷ Kr	1.9	76.3M	845.5	7.3	402.6	49.6	Fission
677.6	^{110m} Ag	10.4	250D	657.8	94.6	687.0	6.4	Activation
687.0	^{110m} Ag	6.4	250D	677.6	10.4	706.7	16.4	Activation
692.4	¹⁰² Rh	1.8	~2.9Y	631.3	56.0	695.6	2.7	Fallout
692.5	¹⁵⁴ Eu	1.7	8.8Y	591.8	4.8	723.4	19.7	Fallout
695.6	¹⁰² Rh	2.7	~2.9Y	692.4	1.8	697.6	45.7	Fallout
696.5	¹⁴⁴ Ce	1.3	285D	133.5	11.1	80.1	1.1	Fallout
697.6	¹⁰² Rh	45.7	~2.9Y	766.9	34.0	695.6	2.7	Fallout
706.7	^{110m} Ag	16.4	250D	687.0	6.4	744.3	4.7	Activation
709.3	¹²⁴ Sb	1.4	60.2D	645.9	7.4	713.8	2.3	Fallout
713.8	¹²⁴ Sb	2.3	60.2D	709.3	1.4	722.8	10.9	Fallout
722.8	¹²⁴ Sb	10.9	60.2D	713.8	2.3	968.2	1.9	Fallout
722.9	¹³¹ I	1.8	8.04D	364.5	81.2	637.0	7.3	Fission
723.4	¹⁵⁴ Eu	19.7	8.8Y	692.5	1.7	756.8	4.3	Fallout
724.2	⁹⁵ Zr	44.1	64.0D	756.7	54.5			Fallout
727.0D	¹³² I	5.4	2.28H	671.6	5.2	728.7	1.1	¹³² Te
727.3	²¹² Bi	6.7	Long	39.9	1.1	1620.7	1.5	²³² Th
728.7	¹³² I	1.1	2.28H	727.0D	5.4	772.7	76.2	¹³² Te
739.5	⁹⁹ Mo	12.1	65.9H	366.4	1.2	777.9	4.4	Fallout
744.3	^{110m} Ag	4.7	250D	706.7	16.4	763.9	22.3	Activation
751.7	¹⁴⁰ La	4.3	40.3H	487.0	45.9	815.8	23.6	Fallout
755.3	²²⁸ Ac	1.3	Long	463.1	4.6	772.3	1.1	²³² Th
756.7	⁹⁵ Zr	54.5	64.0D	724.2	44.1			Fallout
756.8	¹⁵⁴ Eu	4.3	8.8Y	723.4	19.7	873.2	11.5	Fallout
763.1	²⁰⁸ Tl	0.6	Long	583.0	30.9	860.3	4.3	²³² Th
763.9	^{110m} Ag	22.3	250D	744.3	4.7	818.0	7.3	Activation
765.8	⁹⁵ Nb	99.8	35.0D					Fallout
766.9	¹⁰² Rh	34.0	~2.9Y	697.6	45.7	1046.6	34.0	Fallout
768.4	²¹⁴ Bi	5.0	Long	665.6	1.6	786.4D	0.3	²³⁸ U
772.3	²²⁸ Ac	1.1	Long	755.3	1.3	794.8	4.6	²³² Th
772.7	¹³² I	76.2	2.28H	728.7	1.1	780.1	1.2	¹³² Te
777.9	⁹⁹ Mo	4.4	65.9H	739.5	12.1	366.4	1.2	Fallout
778.9	¹⁵² Eu	13.0	13.3Y	444.0D	3.1	867.4	4.2	Fallout
780.1	¹³² I	1.2	2.28H	772.7	76.2	809.8	2.9	¹³² Te

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
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785.5	²¹² Bi	1.1	Long	727.3	6.7	1620.7	1.5	²³² Th
786.4	²¹⁴ Bi	0.3	Long	768.4	4.9	806.2	1.2	²³⁸ U
794.8	²²⁸ Ac	4.6	Long	772.3	1.1	830.6	0.6	²³² Th
795.8	¹³⁴ Cs	85.4	2.06Y	604.7	97.8	801.9	8.7	Fission
802.0	¹³⁴ Cs	8.7	2.06Y	795.9	85.4	1038.6	1.0	Fission
806.2	²¹⁴ Bi	1.2	Long	786.4	0.3	934.0	3.2	²³⁸ U
809.8	¹³² I	2.9	2.28H	780.1	1.2	812.3	5.6	¹³² Te
810.8	⁵⁸ Co	99.5	70.9D	511.0	30.0			Activation
812.3	¹³² I	5.6	2.28H	809.8	2.9	877.2	1.1	¹³² Te
815.8	¹⁴⁰ La	23.6	40.3H	751.7	4.3	867.8	5.6	Fallout
818.0	^{110m} Ag	7.3	250D	763.9	22.3	884.7	72.7	Activation
818.6	¹³⁶ Cs	99.8	13.2D	340.6	48.6	1048.1	79.7	Fission
830.6	²²⁸ Ac	0.6	Long	794.8	4.6	835.6	1.7	²³² Th
834.8	⁵⁴ Mn	100.0	312.2D					Fallout
834.9	⁸⁸ Kr	13.0	2.84H	362.3	2.3	985.8D	1.3	Fission
835.6	²²⁸ Ac	1.7	Long	830.6	0.6	840.4	0.9	²³² Th
840.4	²²⁸ Ac	0.9	Long	835.6	1.7	904.3	0.9	²³² Th
845.5	⁸⁷ Kr	7.3	76.3M	673.9	1.9	1175.5	1.1	Fission
860.3	²⁰⁸ Tl	4.3	Long	2614.4	35.8	583.0	30.9	²³² Th
867.4	¹⁵² Eu	4.2	13.3Y	778.9	13.0	964.1	14.5	Fallout
867.8	¹⁴⁰ La	5.6	40.3H	815.8	23.6	919.6	2.7	Fallout
871.7	¹³⁸ Cs	5.1	32.2M	547.0	10.8	1009.8	29.8	¹³⁸ Xe
873.2	¹⁵⁴ Eu	11.5	8.8Y	756.8	4.3	996.3	10.3	Fallout
877.2	¹³² I	1.1	2.28H	812.3	5.6	954.6	18.1	¹³² Te
884.7	^{110m} Ag	72.7	250D	818.0	7.3	937.5	34.4	Activation
898.1	⁸⁸ Y	92.7	107D	1836.1	99.4			Activation
898.0	⁸⁸ Rb	14.1	17.8M	1836.1	21.4	2677.9	2.0	⁸⁸ Kr
904.3	²²⁸ Ac	0.9	Long	840.4	0.9	911.2	29.0	²³² Th
911.2	²²⁸ Ac	29.0	Long	966.0D	23.2	840.4	0.9	²³² Th
919.6	¹⁴⁰ La	2.7	40.3H	867.8	5.6	925.2	7.0	Fallout
925.2	¹⁴⁰ La	7.1	40.3H	487.0	45.9	919.6	2.7	Fallout
934.0	²¹⁴ Bi	3.2	Long	1120.3	15.0	806.2	1.2	²³⁸ U
937.5	^{110m} Ag	34.4	250D	1384.3	24.3	884.7	72.7	Activation
954.6	¹³² I	18.1	2.28H	877.2	1.1	1136.2	3.0	¹³² Te
964.1	¹⁵² Eu	14.5	13.3Y	1085.9	9.9	867.4	4.2	Fallout
964.6	²²⁸ Ac	5.8	Long	969.0	17.4	911.2	29.0	²³² Th
968.2	¹²⁴ Sb	1.9	60.2D	1045.1	1.9	722.8	10.9	Fallout

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin

969.0	²²⁸ Ac	17.4	Long	911.2	29.0	1459.2	1.1	²³² Th
985.8	⁸⁸ Kr	1.3	2.84H	1141.4	1.3	834.9	13.0	Fission
996.3	¹⁵⁴ Eu	10.3	8.8Y	1004.8	17.9	873.2	11.5	Fallout
1001.0	^{234m} Pa	0.7	Long	766.4	0.2	742.8	0.1	²³⁸ U
1004.8	¹⁵⁴ Eu	17.9	8.8Y	1274.5	35.5	996.3	10.3	Fallout
1009.8	¹³⁸ Cs	29.8	32.2M	1147.3	1.2	871.7	5.1	¹³⁸ Xe
1038.6	¹³⁴ Cs	1.0	2.06Y	1167.9	1.8	802.0	8.7	Fission
1045.1	¹²⁴ Sb	1.9	60.2D	1325.5	1.6	968.2	1.9	Fallout
1046.6	¹⁰² Rh	33.0	2.9Y	1103.2	4.4	766.9	34.0	Fallout
1048.1	¹³⁶ Cs	79.7	13.2D	818.6	99.8	1235.4	19.8	Fission
1050.4	¹⁰⁶ Ru	1.5	372D	511.9	20.7	621.9	9.8	Fallout
1063.1	²⁰⁷ Bi	74.9	32.2Y	569.2	97.8	1769.7	6.9	Fallout
1085.9	¹⁵² Eu	9.9	13.3Y	1112.1	13.6	964.1	14.	Fallout
1099.3	⁵⁹ Fe	56.5	44.5D	1291.6	43.2	192.3	3.1	Fallout
1103.2	^{102m} Rh	2.9	207D	556.6	1.9	628.1	5.5	Fallout
1103.2	¹⁰² Rh	4.4	2.9Y	1046.6	33.0	1112.9	18.9	Fallout
1112.1	¹⁵² Eu	13.6	13.3Y	1085.9	9.9	1212.9	1.4	Fallout
1112.9	¹⁰² Rh	18.	2.9Y	1046.6	33.0	1103.2	4.4	Fallout
1114.3	¹³⁸ Xe	1.5	14.1M	1768.4	16.7	434.6	20.3	Fission
1115.5	⁶⁵ Zn	50.8	244D	511.0	2.9			Activation
1120.3	²¹⁴ Bi	15.0	Long	1155.2	1.7	934.0	3.2	²³⁸ U
1136.2	¹³² I	3.0	2.28H	954.6	18.1	1143.6	1.4	¹³² Te
1141.4	⁸⁸ Kr	1.3	2.84H	1369.4	1.5	985.8D	1.3	Fission
1143.6	¹³² I	1.4	2.28H	1136.2	3.0	1173.3	1.1	¹³² Te
1147.3	¹³⁸ Cs	1.2	32.2M	1009.8	29.8	1343.6	1.1	¹³⁸ Xe
1155.2	²¹⁴ Bi	1.7	Long	1238.1	5.9	1120.3	15.0	²³⁸ U
1167.9	¹³⁴ Cs	1.8	2.06Y	1038.6	1.0	1365.2	3.0	Fission
1173.2	⁶⁰ Co	99.9	5.27Y	1332.5	100.0			Activation
1173.3	¹³² I	1.1	2.28H	1143.6	1.4	1290.8	1.1	¹³² Te
1175.5	⁸⁷ Kr	1.1	76.3M	1740.6	2.0	845.5	7.3	Fission
1212.9	¹⁵² Eu	1.4	13.3Y	1112.1	13.6	1299.2	1.6	Fallout
1235.4	¹³⁶ Cs	19.8	13.2D	818.6	99.8	1048.1	79.7	Fission
1238.1	²¹⁴ Bi	5.9	Long	1155.2	1.7	1281.0	1.5	²³⁸ U
1274.5	²² Na	99.9	2.60Y	511.0	181.0			Cosmic
1274.5	¹⁵⁴ Eu	35.5	8.8Y	1004.8	17.9	1596.6	1.8	Fallout
1281.0	²¹⁴ Bi	1.5	Long	1238.1	5.9	1377.7	4.0	²³⁸ U
1290.8	¹³² I	1.1	2.28H	1173.3	1.1	1295.4	2.0	¹³² Te
1291.6	⁵⁹ Fe	43.2	44.5D	1099.3	56.5	192.3	3.1	Activation

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin

1293.6	⁴¹ Ar	99.2	1.83H					Activation
1295.4	¹³² I	2.0	2.28H	1290.8	1.1	1372.1	2.5	¹³² Te
1299.2	¹⁵² Eu	1.6	13.3Y	1212.9	1.4	1408.0	20.8	Fallout
1325.5	¹²⁴ Sb	1.6	60.2D	1045.1	1.9	1368.2	2.7	Fallout
1332.5	⁶⁰ Co	100.0	5.27Y	1173.2	99.9			Activation
1343.6	¹³⁸ Cs	1.1	32.2M	1147.3	1.2	1435.8	76.3	¹³⁸ Xe
1365.2	¹³⁴ Cs	3.0	2.06Y	1167.9	1.8	1038.6	1.0	Fission
1368.2	¹²⁴ Sb	2.7	60.2D	1325.5	1.6	1436.7	1.3	Fallout
1368.6	²⁴ Na	100.0	14.7H	2754.1	99.9			Activation
1369.4	⁸⁸ Kr	1.5	2.84H	1141.4	1.3	1518.4	2.2	Fission
1372.1	¹³² I	2.5	2.28H	1295.4	2.0	1398.6	7.1	¹³² Te
1377.7	²¹⁴ Bi	4.0	Long	1281.0	1.5	1401.5	1.4	²³⁸ U
1384.3	^{110m} Ag	24.3	250D	1475.8	4.0	937.5	34.4	Activation
1398.6	¹³² I	7.1	2.28H	1372.1	2.5	1442.5	1.4	¹³² Te
1401.5	²¹⁴ Bi	1.4	Long	1377.7	4.0	1408.0	2.5	²³⁸ U
1408.0	²¹⁴ Bi	2.5	Long	1401.5	1.4	1509.2	2.2	²³⁸ U
1408.0	¹⁵² Eu	20.8	13.3Y	1299.2	1.6	1212.9	1.4	Fallout
1435.8	¹³⁸ Cs	76.3	32.2M	1343.6	1.1	2218.0	15.2	¹³⁸ Xe
1436.6	¹²⁴ Sb	1.3	60.2D	1368.2	2.7	1691.0	47.1	Fallout
1442.5	¹³² I	1.4	2.28H	1398.6	7.1	1921.1	1.2	¹³² Te
1459.2	²²⁸ Ac	1.1	Long	1499.0D	1.6	969.0	17.4	²³² Th
1460.8	⁴⁰ K	10.7	1.3E9					Natural
1475.8	^{110m} Ag	4.0	250D	1384.3	24.3	1505.0	13.0	Activation
1499.0D	²²⁸ Ac	1.6	Long	1459.2	1.1	1588.2	3.6	²³² Th
1505.0	^{110m} Ag	13.0	250D	1475.8	4.0	1562.3	1.0	Activation
1509.2	²¹⁴ Bi	2.2	Long	1408.0	2.5	1661.3	1.2	²³⁸ U
1518.4	⁸⁸ Kr	2.2	2.84H	1369.4	1.5	1529.8	10.9	Fission
1529.8	⁸⁸ Kr	10.9	2.84H	1518.4	2.2	2029.9	4.5	Fission
1588.2	²²⁸ Ac	3.6	Long	1499.0D	1.6	1630.5	2.0	²³² Th
1596.5	¹⁴⁰ La	95.4	40.3H	487.0	45.9	2521.7	3.4	Fallout
1596.6	¹⁵⁴ Eu	1.7	8.8Y	1274.5	35.5	1004.8	17.9	Fallout
1620.7	²¹² Bi	1.5	Long	727.3	6.7	785.5	1.1	²³² Th
1630.5	²²⁸ Ac	2.0	Long	1588.2	3.6	1499.0D	1.6	²³² Th
1661.3	²¹⁴ Bi	1.2	Long	1509.2	2.2	1729.6	3.1	²³⁸ U
1691.0	¹²⁴ Sb	47.1	60.2D	2090.9	5.5	1436.7	1.3	Fallout

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
1729.6	²¹⁴ Bi	3.1	Long	1764.5	15.9	1661.3	1.2	²³⁸ U

1740.6	⁸⁷ Kr	2.0	76.3M	1175.5	1.1	2011.9	2.9	Fission
1764.5	²¹⁴ Bi	15.9	Long	1729.6	3.1	1847.4	2.1	²³⁸ U
1768.4	¹³⁸ Xe	16.7	14.1M	1114.3	1.5	1850.9	1.4	Fission
1769.7	207Bi	6.9	32.2Y	1063.1	74.9	569.2	97.8	Fallout
1836.1	⁸⁸ Rb	21.4	17.8M	2677.9	2.0	898.1	14.1	⁸⁸ Kr
1836.1	⁸⁸ Y	99.4	107D	898.1	92.7			Other
1847.4	²¹⁴ Bi	2.1	Long	1764.5	15.9	2118.5	1.2	²³⁸ U
1850.9	¹³⁸ Xe	1.4	14.1M	1768.4	16.7	2004.8	5.4	Fission
1921.1	¹³² I	1.2	2.28H	1442.5	1.4	2002.4	1.1	¹³² Te
2002.4	¹³² I	1.1	2.28H	1921.1	1.2	1442.5	1.4	¹³² Te
2004.8	¹³⁸ Xe	5.4	14.1M	1850.9	1.4	2015.9	12.3	Fission
2011.9	⁸⁷ Kr	2.9	76.3M	1740.6	2.0	2556.0D	13.1	Fission
2015.9	¹³⁸ Xe	12.3	14.1M	2004.8	5.4	2079.3	1.4	Fission
2029.9	⁸⁸ Kr	4.5	2.84H	1529.8	10.9	2035.5	3.7	Fission
2035.5	⁸⁸ Kr	3.7	2.84H	2029.9	4.5	2195.8	13.2	Fission
2079.3	¹³⁸ Xe	1.4	14.1M	2015.9	12.3	2252.3	2.3	Fission
2090.9	¹²⁴ Sb	5.5	60.2D	1436.6	1.3	1691.0	47.1	Fallout
2118.5	²¹⁴ Bi	1.2	Long	1847.4	2.1	2204.1	5.0	²³⁸ U
2195.8	⁸⁸ Kr	13.2	2.84H	2035.5	3.7	2231.8	3.4	Fission
2204.1	²¹⁴ Bi	5.0	Long	2447.7	1.6	2118.5	1.2	²³⁸ U
2217.8	¹³⁸ Cs	15.2	32.2M	1435.8	76.3	2639.4	7.6	¹³⁸ Xe
2231.8	⁸⁸ Kr	3.4	2.84H	2195.8	13.2	2392.1	34.6	Fission
2252.3	¹³⁸ Xe	2.3	14.1M	2079.3	1.4	2015.9	12.3	Fission
2392.1	⁸⁸ Kr	34.6	2.84H	2231.8	3.4	2195.8	13.2	Fission
2447.7	²¹⁴ Bi	1.6	Long	2204.1	5.0	2118.5	1.2	²³⁸ U
2521.7	¹⁴⁰ La	3.4	40.3H	1596.5	96.4	487.0	45.9	Fallout
2556D	⁸⁷ Kr	13.1	76.3M	2011.9	2.9	1740.6	2.0	Fission
2614.4	²⁰⁸ Tl	35.8	Long	860.3	4.3	583.0	30.9	²³² Th
2639.4	¹³⁸ Cs	7.6	32.2M	2217.8	15.2	1435.8	76.	¹³⁸ Xe

TABLE OF γ -RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
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2677.9	⁸⁸ Rb	2.0	17.8M	1836.1	21.4	898.1	14.1	⁸⁸ Kr
2754.0	²⁴ Na	99.9	14.7H	1368.6	100.0			Activation
6129.2	¹⁶ N	68.8	7.13S	7115.2	4.7			Other
7115.2	¹⁶ N	4.7	7.13S	6129.2	68.8			Other

5.5 X-RAY

5.5.1 SCOPE

This section presents a table of X-ray energies which are useful for radiochemical analyses.

A number of nuclides emit X-rays as part of their decay scheme. These X-rays may be counted with Ar proportional counters with Ge planar or n-type Ge co-axial detectors or with thin crystal NaI(Tl) scintillation counters. In both cases, spectral measurements can be made and both qualitative and quantitative information obtained on the sample.

K Shell vacancies are filled by a higher shell election. In the process an energy $E_k - E_x$ is liberated either as an X-ray or an Auger electron. The most important X-ray transitions are designated as,

$$K_{\alpha_1} = K - L_{\text{III}}$$

$$K_{\alpha_2} = K - L_{\text{II}}$$

$$K_{\beta_1} = K - M_{\text{III}}$$

$$K_{\beta_2} = K - N_{\text{III}}$$

$$K_{\beta_3} = K - M_{\text{II}}$$

$$K_{\beta_4} = K - N_{\text{II}}$$

$$K_{\beta_5} = K - M_{\text{IV}}$$

With moderate resolution only $K_{\beta 1}'$ and $K_{\beta 2}'$ can be resolved,

$$K_{\beta 1}' = K_{\beta 1} + K_{\beta 3} + K_{\beta 5}$$

$$K_{\beta 2}' = K_{\beta 2} + K_{\beta 4}$$

The same is true for K_{α} .

$$K_{\alpha} = K_{\alpha 1} + K_{\alpha 2}$$

The present table lists the values for K_{α} , $K_{\beta 1}'$ and $K_{\beta 2}'$. Electron binding energies used in this table were based on the tabulations of Wapstra et al. (1959) and Siegbahn (1965).

REFERENCES

Browne, E. and R. B. Firestone

Table of Radioactive Isotopes

Shirley, V. S. (Editor)

John Wiley and Sons, Inc., New York (1986)

Siegbahn, K.

Alpha, Beta, and Gamma Ray Spectroscopy

North-Holland Publishing, Co., Amsterdam (1965)

Wapstra, A. H., G. J. Nijgh and R. Van Lieshout

Nuclear Spectroscopy Tables

North-Holland Publishing, Co., Amsterdam (1959)

Z	Element	K _u	Energy (keV)	
			K _{B1}	K _{B2}
3	Li	0.05		
4	Be	0.11		
5	B	0.18		
6	C	0.28		
7	N	0.40		
8	O	0.53		
9	F	0.68		
10	Ne	0.85		
11	Na	1.04		
12	Mg	1.25		
13	Al	1.49		
14	Si	1.74		
15	P	2.01		
16	S	2.31		
17	Cl	2.62		
18	Ar	2.96	3.19	
19	K	3.31	3.59	
20	Ca	3.69	4.01	
21	Sc	4.09	4.46	
22	Ti	4.51	4.93	
23	V	4.95	5.43	
24	Cr	5.42	5.95	
25	Mn	5.90	6.49	
26	Fe	6.40	7.06	
27	Co	6.93	7.65	
28	Ni	7.47	8.26	
29	Cu	8.03	8.91	
30	Zn	8.63	9.57	
31	Ga	9.24	10.3	
32	Ge	9.88	11.1	

Z	Element	Energy (keV)		
		K _a	K _{B1}	K _{B2}
33	As	10.5	11.7	
34	Si	11.2	12.5	
35	Br	11.9	13.3	
36	Kr	12.6	14.1	
37	Rb	13.4	15.0	
38	Sr	14.1	15.8	16.1
39	Y	14.9	16.7	17.0
40	Zr	15.7	17.7	18.0
41	Nb	16.6	18.6	19.0
42	Mo	17.4	19.6	20.0
43	Te	18.3	20.6	21.0
44	Ru	19.2	21.6	22.1
45	Rh	20.2	22.7	23.2
46	Pd	21.1	23.8	24.3
47	Ag	22.1	24.9	25.5
48	Cd	23.1	26.1	26.6
49	In	24.1	27.3	27.9
50	Sn	25.1	28.4	29.1
51	Sb	26.3	29.7	30.4
52	Te	27.3	31.0	31.7
53	I	28.5	32.3	33.0
54	Xe	29.6	33.6	34.4
55	Cs	30.8	34.9	35.8
56	Ba	32.0	36.4	37.2
57	La	33.3	37.8	38.7
58	Ce	34.5	39.3	40.2
59	Pr	35.9	40.7	41.8
60	Nd	37.2	42.3	43.3

61	Pm	38.5	43.8	44.9
62	Sm	39.8	45.4	46.6

Z	Element	K _w	Energy (keV)	
			K _{B1}	K _{B2}
63	Eu	41.3	47.0	48.2
64	Cd	42.7	48.7	49.9
65	Tb	44.1	50.4	51.7
66	Dy	45.6	52.1	53.4
67	Ho	47.1	53.8	55.3
68	Er	48.7	55.6	57.1
69	Tm	50.3	57.5	59.0
70	Yb	51.9	59.4	60.9
71	Lu	53.5	61.3	62.9
72	Hf	55.2	63.2	64.9
73	Ta	57.1	65.2	67.0
74	W	58.8	67.2	69.1
75	Re	60.6	69.3	71.2
76	Os	62.4	71.4	73.4
77	Ir	64.3	73.6	75.6
78	Pt	66.2	75.7	77.8
79	Au	68.2	78.0	80.1
80	Hg	70.1	80.1	82.5
81	Tl	72.1	82.4	84.9
82	Pb	74.2	84.7	87.3
83	Bi	76.3	87.1	89.8
84	Po	78.4	89.6	92.3
85	At	80.5	92.7	95.0
86	Rn	82.8	94.7	97.5
87	Fr	85.0	97.3	100.2
88	Ra	87.3	99.9	103.0
89	Ac	89.7	102.6	105.7

Z	Element	K _α	Energy (keV)	
			K _{B1}	K _{B2}
90	Th	92.1	105.3	108.6
91	Pa	94.5	108.1	111.4
92	U	97.0	111.0	114.5
93	Np	99.5	113.9	117.5
94	Pu	102.1	116.9	120.5
95	Am	104.7	119.9	123.6
96	Cm	107.5	123.0	126.9
97	Bk	110.2	126.2	130.2
98	Cf	113.0	129.4	133.5
99	Es	115.9	132.7	136.9
100	Fm	118.8	136.0	140.4
101	Md	122.8	139.4	144.9
102	No	124.8	142.7	147.5
103	Lw	127.9	146.2	151.2
104		130.5	149.7	154.5

5.6 NATURAL DECAY SERIES

5.6.1 SCOPE

Charts of the four heavy element series are given in this section. These are the three natural series and the artificial Am series.

Data for half-lives and energies have been taken from Browne et al. (1986). Energies are given in order of abundance and include only the major emissions. Branching in the chains that amount to one percent or less are also omitted.

REFERENCE

Browne, E. and R. B. Firestone
Table of Radioactive Isotopes
Shirley, V. S. (Editor)
John Wiley and Sons, Inc. (1986)

Principal Members of the Uranium Series

^{238}U (UI) 4.47×10^9 y 4.2 MeV	^{234}U (UII) 2.45×10^5 y 4.7 MeV
9	^{234}Pa (UX_2) 1.17 min 2.3 MeV
^{234}Th (UX_1) 24.1 d 0.2, 0.1 MeV	^{230}Th (Io) 7.54×10^4 4.6 MeV
9	
^{226}Ra (Ra) 1600 y 4.8 MeV	9
^{222}Rn (Rn) 3.825 d 5.5 MeV	9
9	
Alpha Decay 9	^{218}Po (RaA) 3.05 m 6.0 MeV
Beta Deca	^{214}Po (RaC) 19.9 m 0.4-3.3 MeV
	^{210}Po (RaD) 1.64×10^{-4} s 7.7 MeV
	^{210}Bi (RaE) 5.013 d 1.2 MeV
	^{210}Pb (RaF) 138.376 d 5.3 MeV
	9
	^{214}Pb (RaB) 26.8 m 0.7, 1.0 MeV
	^{210}Pb (RaD) 22.3 y 0.02, 0.06 MeV
	^{206}Pb (RaG) Stable

Principal Members of the Thorium Series

^{232}Th (Th) 1.405×10^{10} y 4.0 MeV	^{228}Th (Rd Th) 1.91 y 5.3, 5.4 MeV
9	^{228}Ac (Ms Th II) 6.13 h 0.4-2.2 MeV
^{228}Ra (Ms Th I) 5.75 y 0.01, 0.04 MeV	^{224}Ra (ThX) 3.66 d 5.4, 5.7 MeV
—	—
	9
	^{220}Rn (Tn) 55.6 s 6.3 MeV
	—
	9
	^{216}Po (ThA) 0.15 s 6.8 MeV
	—
	9
^{218}Pb (ThB) 10.64 h 0.3, 0.6 MeV	^{212}Po (ThC D) 2.98×10^{-7} 8.8 MeV
9	^{212}Bi (ThC) 60.6 min 6.1 MeV " , 2.2 MeV \$
Alpha Decay 9 Beta Decay —	9
^{212}Pb (ThB) 10.64 h 0.3, 0.6 MeV	^{208}Pb (ThD) 1/3 Stable
	^{208}Tl (ThC D) 3.053 min 1.0-1.8 MeV

Principal Members of the Actinium Series

^{235}U (AcU) 7.037×10^8 y 4.4-4.6 MeV		
9	^{231}Pa 3.276×10^4 y 4.7-5.1 MeV	
^{231}Th (UY) 1.063 d 0.09-0.30 MeV	—	^{227}Th (Rd Ac) 18.718 d 5.7-6.0 MeV
	9	
	^{227}Ac 21.77 y 0.05 MeV	—
		9
	^{223}Ra (AcX) 11.43 d 5.5-5.7 MeV	
		9
	^{219}Rn (An) 3.96 s 6.4-6.8 MeV	
		9
Beta Decay 9	^{215}Po (AcA) 1.78×10^{-3} s 7.4 MeV	
Alpha Decay —	9	^{211}Bi AcC) 2.14 min 6.3, 6.6 MeV
	^{211}Pb (AcB) 36.1 min 0.5-1.4 MeV	^{207}Pb Stable
		9
		^{207}Ti (AcC'') 4.77 m 1.43 MeV

Principal Members of the Americium Series



